JOINT INSTITUTE FOR NUCLEAR RESEARCH
Veksler and Baldin laboratory of High Energy Physics

FINAL REPORT ON THE INTEREST PROGRAMME

Femtoscopic Correlation of Non-Identical Charged Kaons Using Monte-Carlo Generator: THERMINATOR2

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Participation Period: 08 February - 19 March, 2021

Abstract

Proton-lead collision at the Large Hadron Collider at CERN is a technique for studying the Quark-Gluon Plasma. The correlation for K^+ and K^- using therminator2 needs some edits in the source file responsible for making femtoscopic analysis for such two non-identical particles.

Contents

1 Femtoscopic Correlation

1.1 Purpose of Event Generators

The main aim of Monte-Carlo event generators is to generate and analyze heavy-ion collisions based on the data extracted previously in colliders like the Large Hadron Collider (LHC) and the Relativistic Heavy Ion Collider (RHIC) such as PYTHIA, HERWIG, SHERPA and THERMINTOR2. These generators try to present the most detailed, accurate simulation of particles' collision such as the ROOT files generated by therminator2. The events produced by these generators are primarily probabilistic as it depends on the random possibilities driven from matrix element calculation for a specific point in the space and integration of this point over space [1]. Hence, event generators are designed according to the type of particles needed to be studied as pions and kaons in the case of therminator2.
The following figure [2] shows a collision event for top, anti-top quarks and Higgs boson simulated by a generator for events, while each of the following five colours represents a specific process.

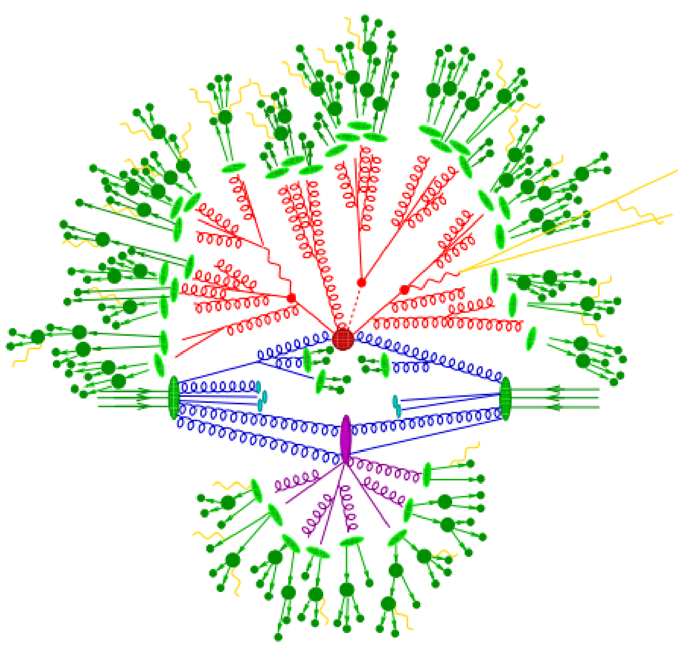

Figure 1: Representation for top, anti-top quarks and Higgs boson

The role of event generators is not shortened only on the production of events based on past data, nevertheless, it helps to indicate to construct experiments for new purposes [3].

1.2 Introduction to Femtoscopic Analysis

The studying of femtoscopic correlation between particles that are identical or non-identical ones in the range of femtometer (i.e. $10^{-15}m$) helps in the identification of the space-time characteristics of a specific particle. The femtoscopic analysis, also, indicates the strong interaction between the particles of interest [4]. Like-particles femtoscopy gives a precise measurement for the size of two ion collision system, in contrast, the unlike particles femtoscopy is used for studying the time-scale of releasing the nucleus fragments during the collision [5].

1.2.1 Correlation of Non-Identical Particles

In the case of non-identical particles, we talk here about particles of different types like $\pi^- p$ or with different charges like $K^- K^+$. This correlation is a result of Coulomb interaction between the two particles and a study for the non-identical particles femtoscopic correlation with the model in a single freeze-out presented [6].

Another study is performed for pion-kaon in Au-Au collision at $\sqrt{sNN}$= 130 Gev [7]. To study correlation of different charged kaons and pions.

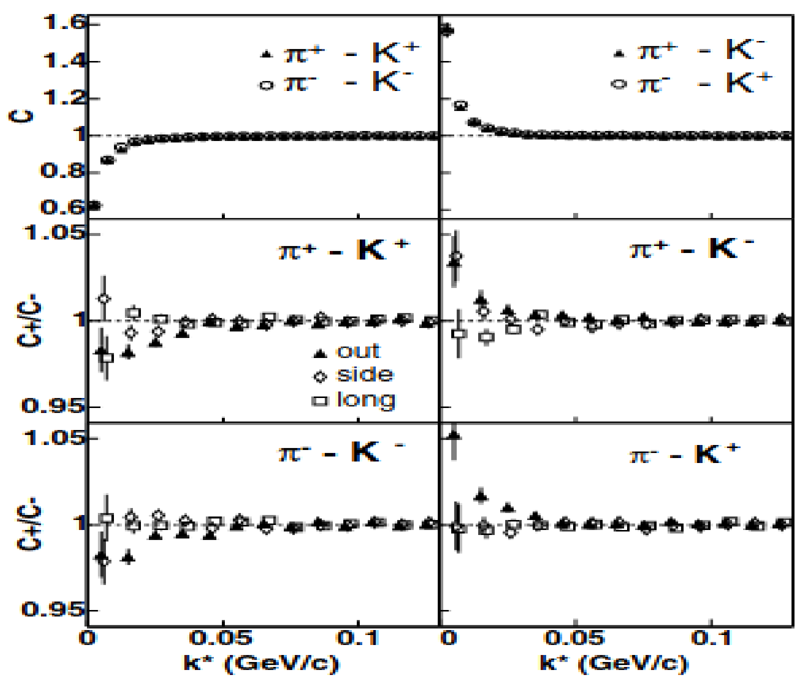

Figure 2: Femtoscopic correlation for pion-kaon

1.2.2 Correlation of Identical Particles

What is meant by identical particles is that we have two particles of the same type and they are similar in all of the properties like mass, charge and quantum numbers like K^+K^+ and $\pi^-\pi^-$.

1.3 Correlation Function

In femtoscopic interactions between nuclei, the correlation between particles can be calculate for two or even three ones. The correlation function [8, 9] is given by:

$$C(q) = \frac{A(q)}{B(q)} \tag{1}$$

Where:
C(q): the correlation function of the two particles.
A(q): numerator is the distribution of the two particles at the same event.
B(q): denominator is the distribution of the two particles in different mixed events of the same centrality.
q: the relative four-momentum.

1.4 Femtoscopic Correlation in therminator2

In the case of therminator2 software, the correlation can be obtained by dividing the numerator and denominator that are included in the root file resulting from running the "./therm2_femto" command. This division is conducted through the construction of a macro file written in C++ as following:

```
#include <iostream>
#include <fstream>
#include <sstream>
#include <TH1D.h>
#include <TH3D.h>
#include <TFile.h>
#include <TGraph.h>
#include <TPad.h>
#include <TCanvas.h>
#include <TImage.h>
#include <TMath.h>
#include <TDatime.h>
#include <math.h>
using namespace std;
TFile* tInRootFile;
TH1D* numq;
TH1D* denq;
TH1D* ratq;
void Correlation()
tInRootFile = new
TFile("path of the root file/name of the file.root");
numq = new TH1D(*((TH1D *) tInRootFile->Get("num1d"))); //nominator
denq = new TH1D(*((TH1D *) tInRootFile->Get("den1d"))); // denominator
ratq = new TH1D(*numq);
ratq->Reset("ICE");
ratq->Divide(numq, denq, 1.0, 1.0); //Divison Process
ratq->SetName("Name");
ratq->SetTitle("Title");
ratq->Draw();
```

2 Technical Edits in THERMINATOR2

The femtoscopic correlation of the K^+ and K^- for any heavy-ion collision between two nuclei can be carried out through therminator2, which requires a typical identification of the types of particles we need them to correlate.

2.1 Calculation of Pair Radii

The Pair Radii of two particles indicates the radius of the interaction space of these two particles. Considering the atom as an example of Coulomb interaction between the electrons and nucleus, in K^+ and K^- case the pair radii of these two charged particles is given by Bohr's radius:

$$a = \frac{\hbar}{\mu\alpha c} \tag{2}$$

Where:
a is the Bohr's radius.
$\hbar$ is the reduced Planck's constant.
α is the hyperfine structure constant.
C is the velocity of light.
μ is the reduced mass of the two particles given by the following relation:

$$\mu = \frac{m_1 m_2}{m_1 + m_2} \tag{3}$$

Where:
m_1: is the mass of the first particle, which is K^+
m_2: is the mass of the second particle, which is K^-

$$\alpha = \frac{e^2}{\hbar c} \tag{4}$$

In terms of natural units choice [10], we have [$\hbar$=c=1] and hence equation (2) will be developed to:

$$\alpha = \frac{1}{\mu\alpha} \tag{5}$$

The value of Bohr radius in Gev is equal to 555.1642066 GeV in the case of studying charged kaons correlation.

2.2 Edits in therm2_femto.cxx and femto.ini Files

Now, some new edits must be made to the files of therminator2 in case of finding the femtoscopic correlation for two other particles other than pions, which are initially stored.

2.2.1 therm2_femto.cxx

As K^- was not defined in the last version of therminator2 and to obtain the correlation for K^+ and K^- we should add and change the following lines:

1. At the beginning of the script, K^- should be defined as [#define KMPID -321].
2. In the third part "# Read Parameters", [else if (tPairType == "kplus-kminus") pair-type = 8;] added to define the two particles aimed to get correlation for. The "pairtype == 8" gives the properties of the two particles given at the
3. In the fourth part "Pair and particle cuts", below the "switch (pairtype)", case 8 is added as the following:
   case 8:
   ptmin1 = PTMIN;
   ptmin2 = PTMIN;
   ptmax1 = PTMAX;
   ptmax2 = PTMAX;
   break;
   Also, At the very end of this part, the following code should be added:
   else if (pairtype == 8)
   partpid = KPID;
   partpid2 = KMPID;
4. In the part number 10 "Save Histograms to file", we have to add:
   - else if (pairtype == 8) sprintf(bufs, "%sfemtoK+-K-%i%s.root",sEventDir.Data(), nbin, onlyprim ? "p" : "a");
     Which is the name of the printed root file.
   - if (pairtype == 1) {
     cnuma->Write();
     cdena->Write();
     num1d->Write();
     den1d->Write();

```
if (docoulomb) {
cnumasph->Write();
cdenasph->Write();
cnumas->Write();
num1dqsc->Write();
num1dc->Write();
}
}
```

5. Lastly, in part number 12 "Temporary file", we should add:

```
else if (pairtype == 7) {
pionac = -555.1642006;
partpid = KPID;
partpid2 = KMPID;
}
```

Note that: The negative sign in the pionac is because we have two non-identical particles.

2.2.2 femto.ini

Consequently for ***femto.ini*** file included in the ***therminator2*** folder, the ***PairType*** in ***line 32*** must edited to equal ***Kplus-Kminus***. Then the software will search in the script for these two particles we chose to correlated and search for those which have the same properties we had defined before.

3 Future Work

Femtoscopy study for K^+ and K^- will be for pPb collision at $\sqrt{S_{NN}} = 5.02$ TeV with centrality of 50-20%

3.1 ϕ Meson Observation

After doing a literature review [11, 12, 13] on the ϕ meson observation in heavy-ion collision, the *phi* meson peak may be observed in the correlation representation for K^+ and K^- as it can decay to the charged kaon and its antiparticle as following:

$$\phi \longrightarrow K^+K^- \tag{6}$$

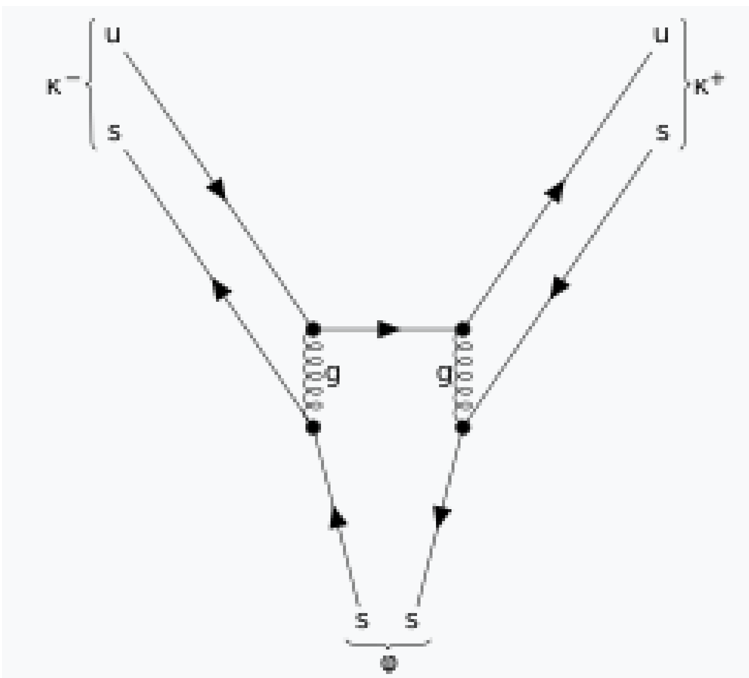

Figure 3: Feynman diagram representation for ϕ meson decay into K^+ and K^-

4 Conclusion

In conclusion, the correlation of two non-identical (K^+ and K^-) particles using THERMINATOR2 was not been applicable as there are some much higher work that should be done to examine the core files of this event generator to get sure that it works well (in our case of studying unlike Kaons correlation).

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